DOCUMENT RESUME

ED 181 078 TM 010 039

AUTHOR Stelmach, George E.
TITLE Perceptual Organization in Motor Learning. Technical Report No. 472. Report from the Project on Studies of Instructional Programming for the Individual Student.
INSTITUTION Wisconsin Univ., Madison. Research and Development Center for Cognitive Learning.
PUB DATE Dec 78
NOTE 60p.

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS *Cognitive Processes; Learning Processes; Literature Reviews; Memory; *Organization; *Perception; Perceptual Development; *Perceptual Motor Learning; Performance Factors; Recall (Psychological); Research Needs; Research Problems; Student Role; Technical Reports; Transfer of Training

ABSTRACT

The role of perceptual organization in motor learning is discussed, the literature is reviewed, and research findings are summarized. Measurement problems are discussed, including observations about motor skill learning. Four experiments are described which compare organized and random movement sequences. It is shown that organization (whether determined by the experimenter or by the learner) improves movement accuracy and reduces retention loss; and that individual memory representations, built up through structured movement sequences, are not locked to that organization, but have generality to other sequences. The importance of cognitive activity in motor skill learning is established. (Author/MH)

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ED181078

Technical Report No. 472

PERCEPTUAL ORGANIZATION IN MOTOR LEARNING

by George E. Stelmach

December 1978

Wisconsin Research
and Development Center
for Individualized Schooling

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PERCEPTUAL ORGANIZATION IN MOTOR LEARNING

by

George E. Stelmach

Report from the Project on
Studies of Instructional Programming for the Individual Student

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December 1978

Research reported here was supported by a Royalty fund award from the Wisconsin Research and Development Center for Individualized Schooling. Portions of the data presented here have been reported at the CIC Symposium on Motor Learning and Control and will appear in G. E. Stelmach (Ed.) Information Processing in Motor Control and Learning. Academic Press, New York, 1978. In the proceedings, G. L. Diewert is a co-author.

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The Wisconsin Research and Development Center is supported with funds from the National Institute of Education and the University of Wisconsin.

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Abstract

While the role of organization is well established in verbal learning, it has received little attention in motor skill learning. The dominated theoretical orientation has emphasized the importance of sensory information and its subsequent memory representation, while regulatory cognitive activity, such as organization, is relegated to a secondary and insignificant role. However, considering the known limitations in human information processing abilities, some organization of sensory stimuli seems essential for even movements of minimal complexity. This manuscript reviews much of the literature on organization and summarizes the research findings. Measurement problems are thoroughly discussed with observations about motor skill learning. Subsequently four experiments are described that compare organized and random movement sequences. It was found that organization, whether determined by the experimenter or by the learner, improved movement accuracy and reduced retention loss. Further, it was shown that individual memory representations, built up through structured movement sequences, are not locked to that organization but have generality to other sequences. While the present research provides only a beginning, the data clearly establish the importance of cognitive activity in motor skill learning.

Introduction

Organization is a topic that has received much discussion but very little substantive or systematic investigation in the motor learning area. Organization has been extensively examined by verbal psychologists such as Tulving, Mandler, and Bousfield, but researchers in the motor area have not yet made similar progress. This paper is addressed to this theoretical and investigative void in motor organization.

Psychomotor research to date has been almost entirely SEQUENTIAL-RANDOM (S-R) and feedback oriented (see Gentile & Nacson, 1976). In most instances, the research relevant to organizational theory has dealt primarily with response or output organization. Contemporary work on motor programs (Keele, 1973; Schmidt, 1975) and schema formation (Pew, 1974; Schmidt, 1975) has failed to address the effects of organization prior to movement execution. Concurrently, the theoretical emphasis has been on a feedback-based learning process where the learner plays a passive role. The historical emphasis in motor learning has been on the sensory consequences of movement. There has been little room for a cognitive or a dynamic view of motor learning. Conversely, it is proposed that learning is dynamic and the learner, in fact, can add much to a learning process based on feedback through his or her perceptions of the environment and development of strategies, plans, etc. Perception is so crucial to the human organism that it is imperative not to limit research on organization to the output side of an

information processing system but also to consider the establishment of memory representation that must precede movement execution. It is therefore proposed that the organizational processes that aid memory representation be termed perceptual organization.

In light of the present use of the term organization, it is crucial to explain the more limiting term of perceptual organization. This clarification can be made by use of any of the contemporary stage models of movement information flow (e.g., Pew, 1974; Welford, 1977). Information in such a model can be conceptualized as moving serially or parallel from perception to other stages such as response organization. Perception precedes all other processes in sequence. Therefore, it makes theoretical and pragmatic sense to deal with perceptual organization before attempting to understand other processes further along in the sequence. Since response is tied to perception or perception is tied to action, output or response organization would be a function of any organizational benefit in the perceptual or memory mode. Therefore, it can be concluded that perceptual organization research is a current requirement or a prerequisite to examination of response organization. This is not to say, however, that perception and response are strictly separate. We only wish to focus our review on the processes establishing memory representation, not those that produce movement in relation to those representations.

Definitions of Organization

Tulving (1968) defined organization in the following way, "The definition of the concept is implicit or confined to a single operational criterion, i.e., output consistency or negative part-whole transfer. . . . This is seen in outputs not common to the input" (p. 15). Mandler (1967a) said a set of objects or events is organized when a consistent relation among the members of the set can be specified and, specifically, when membership of objects or events in subsets is stable and identifiable. Mandler further stated that organization has occurred when relations have been established and partitioned into subsets. Another definition was offered by Bower (1970), "Organization is a cognitive process and these processes group and relate and are the basis of learning" (p. 19).

The definitions just presented represent ways that verbal psychologists conceptualize organization. It should be noted that the concepts differ very little in meaning and differ mostly in scope. What is needed, however, is an operational definition that will facilitate examination of perceptual motor organization. Therefore, perceptual motor organization will be defined, in lieu of extensive research and based in part on verbal theories, as a cognitive process which assimilates memory representation into a close, meaningful relationship resulting in a more stable memory structure than a single less associated representation.

First, since a more stable memory implies better access to memory "traces," an increase in organization should be accompanied by improved performance (e.g., Tulving, 1962). Second, the relationships are stable

over time and therefore any structure or organization should be observable at recall or reproduction. This hypothesis is in accordance with the evidence that subjects often impose a structure or organization on to-be-remembered items. Third, even in the absence of improved performance, organization may occur in that structure and need not always be linked to measureable performance change.

The Role of Organization

The question that comes to mind at this point concerns the necessity of, or the role of perceptual organization. It is well known and accepted that a human is a limited information processor (e.g., Broadbent, 1958) with respect to both the absolute amount of information that can be processed and with respect to processing over time. Further, it is thought that perceptual organization (often referred to by others as chunking or coding) is necessary, if not essential, to allow processing of stimuli of even minimal complexity and load. In this way, structure or organization presented to or determined by the subject permits processing of large amounts of information and possibly better processing of smaller amounts of information within the bounds of the limited capacity model.

The following section provides a brief historical sketch of organization research relevant to the present topic of perceptual organization. This will be followed by discussions of how organization can be measured, how it can be presented, and how it has been examined within the context of motor behavior.

History of Organizational Research

While more thorough historical discourses are available (Bower, 1970; Mandler, 1967a; Tulving & Donaldson, 1972), it is enlightening to have a general knowledge of the evolutionary form of nonmotor (verbal) research.

Many researchers have pointed out the recent shift of emphasis in psychological research. For example, Broadbent (1971), Miller, Galanter, and Pribram (1960), and Postman (1972) have all addressed themselves to the progression of psychological theory and methodology from SEQUENTIAL-RANDOM (S-R) bond and habit strength concepts to contemporary cognitive and process oriented theories of organization (Miller, 1956a; Tulving, 1962), coding (Melton & Martin, 1972) and schema formation (Bartlett, 1932; Schmidt, 1975). Just as psychology in general had adopted an active, organizational focus, so had the specific area of verbal psychology. Associationistic theory has as its basic premise that a human is a passive transmitter of information and S-R bonds and ultimately organization are established by repeated exposure to such S-R bonds. The crucial point is that a human is a passive processor in the sense that the person does not actively impose or contribute to the learning process. This approach would take the view that organization depends on association.

The Organizational view of memory and learning has its roots in Gestalt psychology--specifically, the principles of organization and perceptual grouping. Advocates of Gestalt psychology emphasized

how memory traces changed over time with respect to neural interaction and organization. Four basic tenets of the Gestalt view will be listed for understanding how perceptual motor organization may function.

First, organization depends largely on the initial perception of events. Second, the form of organization is correlated to the commonalities of the component units or events. This implies that an optimal or natural organization exists for all or any given situation. Third, availability of past experiences for recall depends on memory strength. Fourth, accessibility of memory representations for recall depends on the commonality between memory units and current stimuli. Although all four points have relevance to perceptual motor organization, the present emphasis will be on grouping, perception, and optimal organization. Further, with respect to the theoretical orientation of Organizational psychology, it is thought that a human can develop rules and plans for perception and storage in memory and can actively construct, reconstruct, and alter memory. An advocate of this approach might state that associations occur because of organization, not as an antecedent of organization.

Paralleling the shift from Association-based to Organization-based memory is a shift from serial and paired associate learning to free recall methodology. Although these methodologies differ theoretically, they have all been employed to some extent to investigate verbal organization. Since the free recall paradigm has been

the most productive and enlightening, the paragraphs to follow will only briefly describe serial and paired associate learning paradigms. A more lengthy discussion of free recall theory and design will follow.

Serial and Paired Associate Learning

In serial learning, the subject is presented with a serial list of items and is then asked to recall those items in the same order (see reviews in Bower, 1970; Mandler, 1967a, 1967b; McGeoch & Irion, 1952). Since this procedure is characterized by both input and output inflexibility, it is not clear how the subject is organizing. Therefore, it would be impossible to examine how the subject organizes except by inference from recall performance. However, "performance structure," such as parts of a serial list being recalled relatively better than other parts, or even over-all consistency may allow indirect speculation as to the nature of possible perceptual organization constellations. Alternately, experimenter presented organization (EPO) could be directly examined by presenting lists of varying serial organization or structure and then observing performance differences.

For paired associate learning, the usual methodology involves presentation of word pairs. Then the subject is presented with one word of a pair and he or she is asked to recall the other word of the pair. This procedure has been used more frequently by contemporary researchers (e.g., Battig, 1966; Glanzer, 1962; Segal & Mandler, 1967; Underwood & Schulz, 1960; see reviews in Bower, 1970; Mandler, 1967a)

to investigate organization. Interest has been directed at the organizational processes needed for grouping, clustering, and mnemonic links to determine the differential accessibility of the words within a pair and to determine the structure of the pairs themselves in memory. Just as was noted for serial learning, however, structure and inflexibility is present at both input and recall, limiting application to EPO-type questions. Again, inference about subject discovered organization (SDO) must predominantly rely on the indirect evidence of performance measures.

Both serial and paired associate paradigms present at least two major problems to the investigation of organization. First, as mentioned above, without freedom to recall in the order the subject finds to be optimal, the results are confounded with respect to EPO and SDO. Only performance change can be measured in this paradigm. Second, although this point was not explicitly made before, structure imposed by the experimenter at input, such as a serial list and/or word pair followed by a similarly structured recall order, will mask any SDO effects. Nevertheless, recent work has lead to an experimental procedure, termed free recall, which attempts to circumvent these problems.

Free Recall

Free recall paradigms usually involve random presentation of test items after which the subject recalls or reproduces, in any order, as many of the items he or she can remember. This procedure

has become popular since researchers have been able to examine how the subjects' organization correlates with performance; in fact, even if exact free recall procedures are not employed, free recall theory prevails.

This paradigm has been pioneered by Tulving (1962, 1964, 1965, 1966) based on the work and theoretical developments of Bousfield (1953), Cofer (1959), and Miller (1956a, 1956b). A series of experiments by Tulving exemplifies a logical approach to measurement of organization, to investigation of the organization versus repetition issue, and to determination of organization and performance covariance. It is of particular interest that Tulving makes use of paired and serial tasks when appropriate even though free recall thoughts and theories predominate this thinking.

The classic study on organization was undertaken by Endel Tulving at the University of Toronto in the early 1960's (Tulving, 1962). To determine the way in which subjects grouped or related words at recall he developed a measure of subjective organization (SO). SO is derived in such a way that as consistency of recall order from trial to trial is maintained, SO is increased. The subject's task in the course of experimentation was to attempt to recall as many words as possible from a random list of 16 unrelated words presented in a free recall experiment on each of 16 trials. As would be expected, performance improved from 5 or 6 correct to close to perfection after 16 trials. The interesting finding, however, was that even though the subjects were free to recall in any order and presentation

order varied randomly from trial to trial, subjects tended to establish and maintain similar recall orders. Further, SO increased significantly over the 16 trials. Tulving concluded that since organization and performance were correlated, it is not unreasonable to posit that SO causes improved performance.

One must be cautious, however, in proposing a causal relationship between organization and performance since a significant correlation does not necessarily denote causation. Studies by Dallett (1964) and Tulving (1965) apply directly to this question of causality. In a first experiment, Tulving (1965) presented two groups of subjects in a free recall experiment with lists of words either characterized by high organization or low organization, respectively. These lists were derived from Tulving's 1962 experiment and SO was used as a criterion for levels of organization.

The high organization group learned the words much faster and more faithfully retained the input order. The low organization group took much longer to learn the words and not surprisingly attempted to adopt the order presented to the other group even though they had never been exposed to that order. A second experiment in the same study found evidence based on converging operations using a serial anticipation (serial learning) task. Subjects in the high organization group learned much faster. Clearly then, the relationship between organization and performance is causal since manipulation of organization directly affected performance.

Tulving (1966) provided evidence on how organization and performance interact with repetition. Two experimental groups were given the task of reading 22 pairs of items in 6 continuous trials. One group read the words that were to be memorized later, while the control group was presented with words unrelated to those that they would later memorize. Since the two groups did not differ in later attempts at recall and memorization, Tulving suggested that repetition alone is not the crucial factor in memory storage. In a follow-up experiment from the same study, Tulving found that learning part of a list of words before learning the whole list retards learning of the whole list, while prior learning of irrelevant words had no effect on learning in a control group. One explanation of this finding is that the organization developed from the part-list is not appropriate to the whole-list; therefore, to learn the whole-list the subject must reorganize units already in memory. Again, the structure or organization of practice appears to be the crucial factor superceding unstructured practice or repetition.

In summary, organizational research is becoming dominated by free recall theory and experimentation, while serial and paired associate learning are receiving decreasing interest, but are still of use in certain situations. The question remains, however, as to which procedure or procedures are best for investigation of perceptual motor organization. Even though movements are serial or paired by nature of their use in execution of movement, any preconceived

experimental procedure, other than totally random or subject-controlled, superimposes a structure when that specific structure may not be optimal or even desired in the free recall situation. If the experimenter wishes to work within this framework, he or she must be aware of this problem and be prepared to deal with it adequately, especially if he or she chooses to work with structured inputs. Therefore, perceptual motor research faces the dilemma of choosing a procedure based on verbal work where free recall theory is probably best, or to implement totally new procedures along with verbal paradigms. The best strategy appears to be the latter, since the skilled researcher can prevent many problems of verbal research while instituting procedures appropriate to motor memory and perceptual systems. In any case, whichever research tack is undertaken, measurement of organization will be a crucial topic.

Measurement of Organization

Essential to this review and to future research is an understanding of how organization has been or could be measured. Based on general experimental procedures, an unstructured input can be presented and then recall or reproduction structure and/or performance measured; in this situation we are dealing with SDO. Alternately, a structured input can be presented, then reproduction structure and/or performance measured; here we are dealing with EPO. From these basic conditions, various measures of organization have been formulated. Other than qualitative measures of grouping or relating, or even

simple observations of consistent patterns and direct performance measures, various ingenious measures of organization are available.

Intertrial Repetition and Clustering

Clustering measures were proposed by Bousfield (1953) which he defined as the sequential occurrence in free recall paradigms of two items belonging to a category present in the stimulus list. The number of repetitions in a cluster is therefore one less than the number of items in the cluster.

Intertrial repetition is a term proposed by Bousfield. Since it is very similar to Tulving's (1962) subjective measure, its description will be incorporated into the following paragraph. Exact descriptions of intertrial repetition and subjective organization can be found in an excellent paper by Bousfield and Bousfield (1966).

Subjective organization (SO) (Tulving, 1962, 1968) is a measure based on the constancies in response orderings which develop in a series of free recall trials when the order of presentation is changed from trial to trial. It is a measure based on information theory which reflects noise in an information transmission situation, i.e., information or structure present at recall that was not present at input. In essence, it is an index based on a ratio of obtained organization relative to the total possible organization. Both SO and intertrial repetition reflect consistency or organization imposed on the input information by the subject, constrained by the amount of structure

that is inherently present in the input at time of presentation.

There are some problems, however, with these measures. Even though performance approaches perfection, the measures of organization rarely surpass 50% (Postman, Burns, & Hasher, 1970). This implies that organization as indexed by output organization may play a modest role in performance or that the measures used are only partial indices of the degree of organization. As Postman (1971) pointed out, organization may not be directly reflected in output consistency and only in certain limited situations, such as sequential recall tasks, may organization be properly reflected. Stated another way, the very way in which the subject recalls the items, one at a time, limits us to the type of measure of organization that can be implemented. For example, SO and intertrial repetition do not reflect clustering in a "spatial" sense because recall is always sequential.

Another problem is that, even though performance is often correlated to SO and intertrial repetition, by use of instructions the measures of organization can be increased without simultaneously affecting increases in performance (Mayhew, 1967; Puff, 1970). It appears that the experimenter's instructions can affect the degree to which organization can account for performance change.

Transfer

Tests of transfer provide an alternate experimental avenue to assess the functional significance of subjective organization with respect to the nature and form of the memory structure.

Although transfer can be examined in light of both subjective groupings and associations (Postman, 1972), only subjective groupings will be considered here. Postman (1972) further stated:

> Studies of transfer between successive free recall tasks bring into focus the assumption that speed of learning depends on the particular structure that has been imposed on the materials during acquisition. To sharpen the prediction, it becomes useful to add the further assumption that for each subject learning a given list of items there is an optimal organization that will serve to maximize his performance. Prior practice that established groupings inconsistent with the optimal structure should, therefore, be a source of interference. One important implication of this hypothesis is that there should be negative transfer from part-list to whole-list learning when the items are drawn from a pool of unrelated words: the higher order units established during part-learning should be less than optimal for the mastery of the total list (Postman, 1972).

Even though transfer effects have been found (Bower & Lesgold, 1969; Tulving, 1966), there are alternate explanations of some merit. Roberts (1969) suggested that the deficit in performance may be produced by the subject's failure to give an adequate amount of attention to all items during both input and output. Tulving and Osler

(1967) argued that the deficit may be due to failure to discriminate between the items presented first and the items presented last. Nonetheless, transfer studies appear to reveal much about organization. In fact, recent researchers have begun to look at positive transfer as a new approach to investigation of organization (see Bower, 1970; Tulving, 1968).

Measurement of Perceptual Motor Organization

How could organization of movement information be measured? If random movements are presented for recall, a measure of organization such as SO could be used on the order of reproduction. Measures based on extensive new research could be developed which are sensitive to nonsequential structures and are appropriate to motor organization. Alternately, for structured inputs, both consistency and performance may be indicative of organization but only where the structure is present and not immediately apparent such as in a list of words containing items from only four categories (e.g., Bousfield, 1953). Otherwise, only the effects of EPO can be considered. In any event, when linear positioning tasks are employed, qualitative description of trial to trial reproduction order appears to be complete and sufficient due to the simplicity of the task.

With respect to transfer interference, this appears to be a promising procedure. Just as researchers use capacity and structural interference to determine storage codes (Diewert, 1975), interference could also be used to examine the memory structure when the experimental

procedures prohibit measurement of output consistency such as when the reproduction order is fixed by the experimenter. One approach may be to interpolate movements ordered in various ways between presentation and reproduction of movements. It should be expected that a constellation of movements most similar to how the subject is organizing will maximally disrupt performance and/or learning (see Melton & Martin, 1972). Therefore, it seems best to use a multifaceted approach based on both structured and unstructured inputs depending on the question of interest. Structured inputs appear to be indicative of EPO, while unstructured inputs tell us more about the role the subject plays in manipulation and perception of input information, SO.

Experimenter Presented Organization and Subject Discovered Organization

Postman (1972) suggested that a separation of environmental or Experimenter Presented Organization (EPO) and Subject Discovered Organization (SDO) is necessary based on the increasing criticism of experiments that present subjects with organized instead of random information. An EPO experiment usually consists of a list of words to be recalled which has an organization structure. An example of this procedure is found in the classic study by Bousfield (1953). He presented subjects with a list of words which had four obvious categories for classification. In recall it was found that the resulting organization (clustering) was above a chance level.

Bousfield concluded that the clustering was evidence for the operation of organization; however, as Bousfield mentioned, there are some alternate explanations that link the clustering to an association-based mechanism called habit strength. In this respect, Postman (1972) criticized this type of study based on the premise that explanation of the findings need not include subjective organization-based mechanisms. This critique is based on the fact that clustering tendencies can be explained by processes such as response contiguity and information reduction. Moreover, it is implicit that the subject using EPO does not have to select his or her own organizational plan. He or she needs only to observe what organization is present, store it, and transmit the structure to recall to facilitate performance. Therefore, EPO experiments only allow inference on the use of organization, but not inference on the formation of organization.

Conversely, SDO experiments employ theory and methodology which seems best to investigate the actual organizational process where subjects are influenced as little as possible by list structure or method of presentation. Tulving (1962) clearly revealed this approach in a free recall experiment discussed earlier. The experiment was similar to Bousfield's (1953) except the words on the list presented for recall were unrelated, i.e., there was no obvious, inherent structure. The results indicated that the subjects were clustering identical words in the same way for each trial. In this type of experiment it is clear that the subject has to rely on his or her

own organization which can be used with the list of words, and cannot rely on an experimenter presented plan. This study, as did Bousfield's (1953), found that as performance (percent correct) increases, there is a concomitant increase in SO indicating that organization, as measured by clustering or redundancy, is an important process in memory. Further, even though EPO is avoided as much as possible, the subject was still able to organize. This strongly supports using unstructured inputs to determine the organizational ability of subjects.

Postman (1972) summarized the difference between EPO and SDO as follows:

> When a known structure is imposed on the input by the experimenter and is reflected in the output, it becomes far less clear what inferences can be legitimately drawn about the role of organizational processes (Postman, 1972).

In addition, Postman believes that along with learning by association, the improved recall and clustering in EPO experiments could be brought about by response contiguity or "learning by rote," e.g., the input structure is transmitted to storage and is then recalled with a minimum of cognitive processing required by the subject.

At this point it appears that the unstructured, free recall paradigm is best for investigation of verbal organization. However, the criticism of EPO designs arises in verbal research and therefore

may not have the same problems in motor behavior. Perhaps the dilemma can be resolved by considering two possible questions that an experimenter may ask: (a) What effect does organization have? (b) How does a subject organize? If a researcher seeks to answer the former question, the best strategy may be to structure the environment and examine performance. With respect to the latter question, the preceding discussions support use of SDO designs. SDO designs as defined are of merit because the subject must impose his or her own preference for organization. This is illustrated by Tulving (1962), who reported that even though subjects tended to organize in a similar manner, the SO measures indicated that organization had intrasubject properties, i.e., each subject had some form of unique classification.

Verbal research clearly favors SDO experiments. However, the motor area does not have a research base on which to justifiably favor either EPO or SDO. This being the case, future research in motor learning should use whatever approach is best suited to answer the question of interest.

Current Work in Motor Learning Relevant to Perceptual Motor Organization

As mentioned in the Introduction, very little work has been done on perceptual motor organization. The research that has been conducted has stressed organization for movement execution. Nevertheless, there is some research that bears directly on this topic. Although there are numerous studies of peripheral interest, the

preliminary work conducted by Marteniuk (1973) and Roy and Diewert (1975, Note 1) plus the extensive work done at the Motor Behavior Laboratory at the University of Wisconsin (Stelmach & Kelso, Note 2; Stelmach & McCracken, Note 3) supported the notion that pre-movement organization or strategy formation is a potent independent variable. Almost without exception, a self-terminated movement or a movement whose relationship to other movements is known, is reproduced better than movements lacking pre-movement organization or strategy. Reviews of these preselected versus constrained versus passive movement studies can be found in Stelmach and Kelso (Note 2) and Roy and Diewert (1975).

One interpretation of these results is that active or preselected movements have reliable efferent information, thereby facilitating the improved performance. Alternately, as suggested by Roy and Diewert (1975, Note 1) and supported by the present authors, the performance differences can also be attributed to strategy or organization since e. erence alone cannot explain the experimental findings with respect to passive movement where efference is not present.

Nacson, Jaeger, and Gentile (1972), as well as Shea (1977), found that verbal labels or knowledge of movement relationships given to subjects resulted in improved reproduction performance as well as differential performance patterns. Again these results suggested that movement reproduction depends on more than movement-generated feedback.

The studies discussed above suggest a dynamic role for the subject as indicated by an ability to supplement feedback by higher order strategies and organizational mechanisms. In light of the contemporary dichotomy of S-R and Organizational psychology, the Organizational or Cognitive view has support. Therefore, the research section to follow will begin to examine the feedback versus organization issue and its duplication and generality to motor learning.

Perceptual Organization: Experimenter Presented and Subject Discovered Organization

Experimenter Presented Organization

The experiment by Nacson (1973) suggested that the learning of movement information is not merely a function of repetition or feedback. Nacson provided evidence that the order of movement presentation or organization facilitated learning and retention since performance during both knowledge of results (KR)-trials and KR-withdrawal trials was better than movements that were randomly presented. The interpretation presented by Nacson (1973) and by Gentile and Nacson (1976) centered around active organization of movement information based on recognition of the number of movements and equal interval sizes between movement end-points.

An attempt was made to replicate the Nacson (1973) findings. Three experimental groups (n = 6; all between-subject groups reported in this paper, except where otherwise noted, were of this size) were presented movements of length 10, 20, 30, 40, and 50 cm on a

linear positioning apparatus. The sequential group (SEQUENTIAL-SEQUENTIAL) received the order 10-20-30-40-50; the long-short group (LONG-SHORT) received the order 50-10-40-20-30; the random group (RANDOM-RANDOM) received a different order in every trial block.

Each trial block consisted of reproduction attempts in the order specified by the experimental group. Any one trial within a block consisted of the blindfolded subject moving the positioning handle to a stop placed at the appropriate position followed by a reproduction attempt with the stop removed. In all instances, the experimenter returned the positioning handle to the start position. After each block of 5 trials, each movement had been presented an equal number of times. All subjects received a total of 10 trial blocks. During the first 6 blocks, or the learning phase, verbal KR to the nearest millimeter was given. The remaining 4 blocks, or withdrawal phase, consisted of trials where KR was not given. During the KR phase, subjects were instructed to reduce errors as much as possible; for the withdrawal phase, subjects were requested to attempt to keep reducing errors in reference to what they had learned during the KR trials.

Replication of the Nacson (1973) results would be revealed by a difference between experimental groups and/or an interaction with trials. Although there were significant effects in absolute error (AE) and constant error (CE), these were related only to reduction in error over learning trials and differential CE effects for each movement length. Neither of the effects necessary to support Nacson

was found. One explanation may be the present use of a linear slide; Nacson employed a curvilinear apparatus which may have somehow facilitated organization. In addition, since the Nacson study was never reported in full, it is possible that the failure to replicate was a function of experimental instructions.

Organized movement sequences may improve performance and learning only if, as Nacson implies (see Gentile & Nacson, 1976), subjects are aware of the organization and interval sizes. During debriefing in the experiment just discussed, 3 of 6 subjects in the SEQUENTIAL-SEQUENTIAL and LONG-SHORT groups noticed the presentation orders, while not one subject knew that the movements were equidistant. These reports suggested that one way to ensure maximum benefit of EPO is to direct, through instructions, the subjects to attempt to determine the movement sequences and lengths. Therefore, this experiment attempted to ascertain if the effects of EPO are realized when the subject actively seeks to determine and use the structure and order presented.

The procedures were the same as described earlier except that the LONG-SHORT group was not tested since organization effects were minimal. The number of KR trial blocks was increased to 10 and the number of withdrawal blocks to 6. Subjects were reminded to attempt to determine if a consistent order of presentation was used and to try to ascertain the end-point interval sizes before beginning the experiment and after every 2 trial blocks. It is important to note that each group received identical instructions.

For the learning phase in AE, there were significant differences between Groups, Movements, and Trials as well as a 3-way interaction ($p < .01$). The Groups x Trials interaction is presented in Figure 1. In CE, the effects were due to larger positive bias at 30 cm especially due to the RANDOM-RANDOM group.

All effects in withdrawal for AE were significant ($p < .005$) except the Movements x Trials interaction. As before, error increased then decreased as movement length increased. The Groups x Trials interaction is also presented in Figure 1. For CE, the effects were primarily due to positive bias for the 30 cm movement.

Examination of the results supported the hypothesis concerning the role of instructions or direction of attention in perceptual motor organization. The SEQUENTIAL-SEQUENTIAL group was markedly superior in both the learning and withdrawal phases. In fact, the AE scores in the withdrawal phase remained remarkably steady for the 6 trial blocks tested. Further, all subjects in the SEQUENTIAL-SEQUENTIAL group immediately discovered the order. By trial 10, all but one subject stated interval sizes were equal. Therefore, the Nacson (1973) results were replicated only when specific instructions to use the EPO were given.

The previous experiment clearly demonstrated that the structure or organization of practice is a potent factor in motor learning. However, it is important to know if performance on any one movement is maintained outside of the sequential presentation order. If

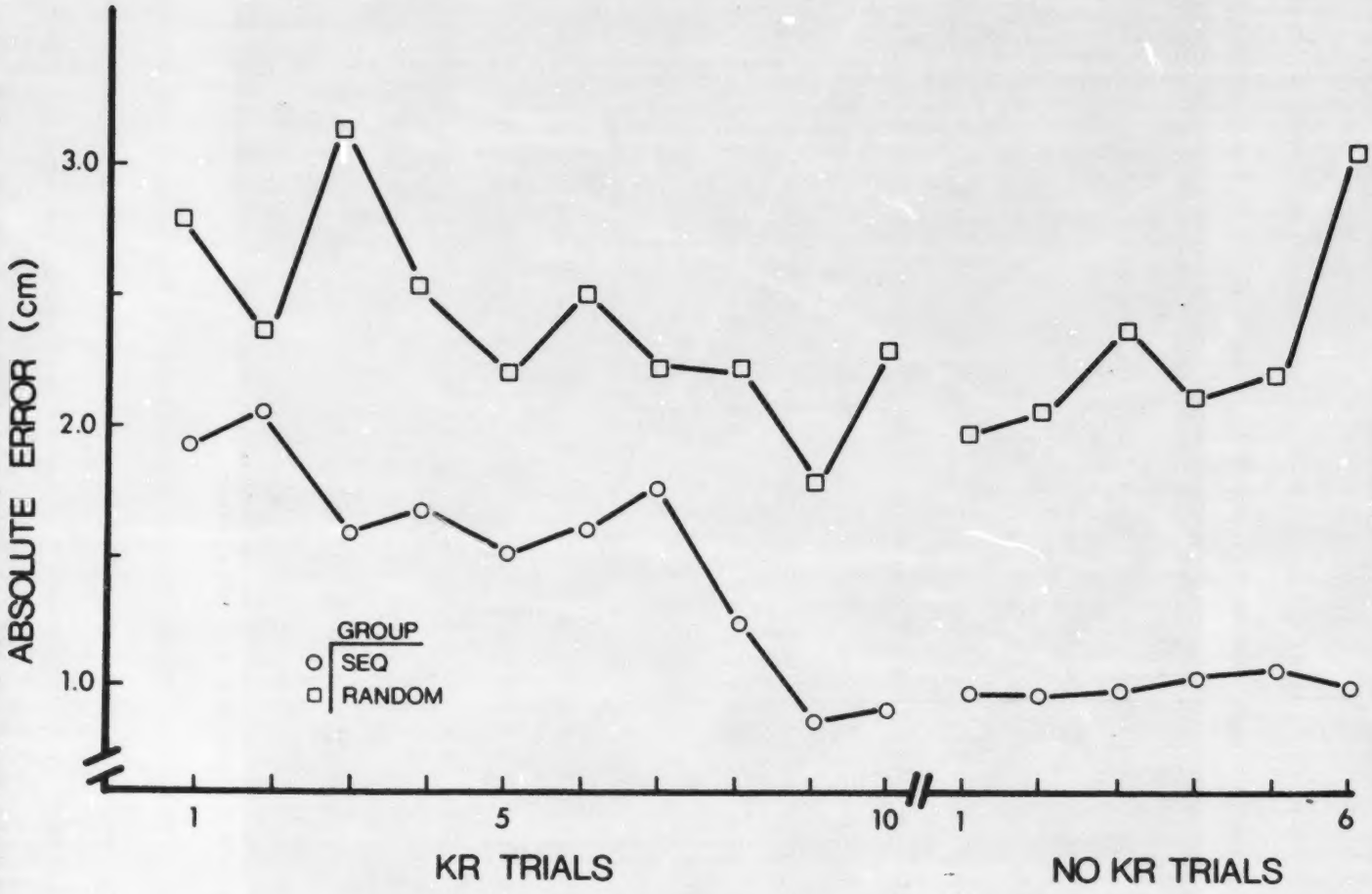

Figure 1. Absolute error as a function of KR Trials (learning phase) and no KR trials (withdrawal phase) for both SEQ (SEQUENTIAL-SEQUENTIAL) and RANDOM (RANDOM-RANDOM) groups.

performance is tied to the position in a sequence, then the organization examined here lacks generality and implies that an intact, rigid memory constellation has been established. On the other hand, if performance is not affected by removal of the structure, EPO is a potent process facilitating individual memory representation. If this is the case, the implication for generality and application of memory units into a new context is clear.

The next experiment attempted to answer this question by having subjects learn under the SEQUENTIAL-SEQUENTIAL conditions, then switch to random orders in the withdrawal phase and similarly learn under random orders and switch to SEQUENTIAL-SEQUENTIAL conditions in withdrawal. The procedures and number of trials presented was the same as in the replication of the Nacson (1973) findings. The two experimental groups were labelled SEQUENTIAL-RANDOM (S-R) and RANDOM-SEQUENTIAL (R-S) depending on the position of organized trials. The SEQUENTIAL-SEQUENTIAL (S-S) and RANDOM-RANDOM (R-R) groups were also retested.

For the learning phase in AE, the Groups, Movements, and Trials effects were significant ($p < .001$). The Trials effect was caused by decreasing error and the Movement effect by error increasing with the length of the movement tested. Figure 2 clearly displays the Group differences. First, note that SEQUENTIAL-SEQUENTIAL and RANDOM-RANDOM groups are convincing replications of the data presented in Figure 1. Specifically, note that the learning phase of

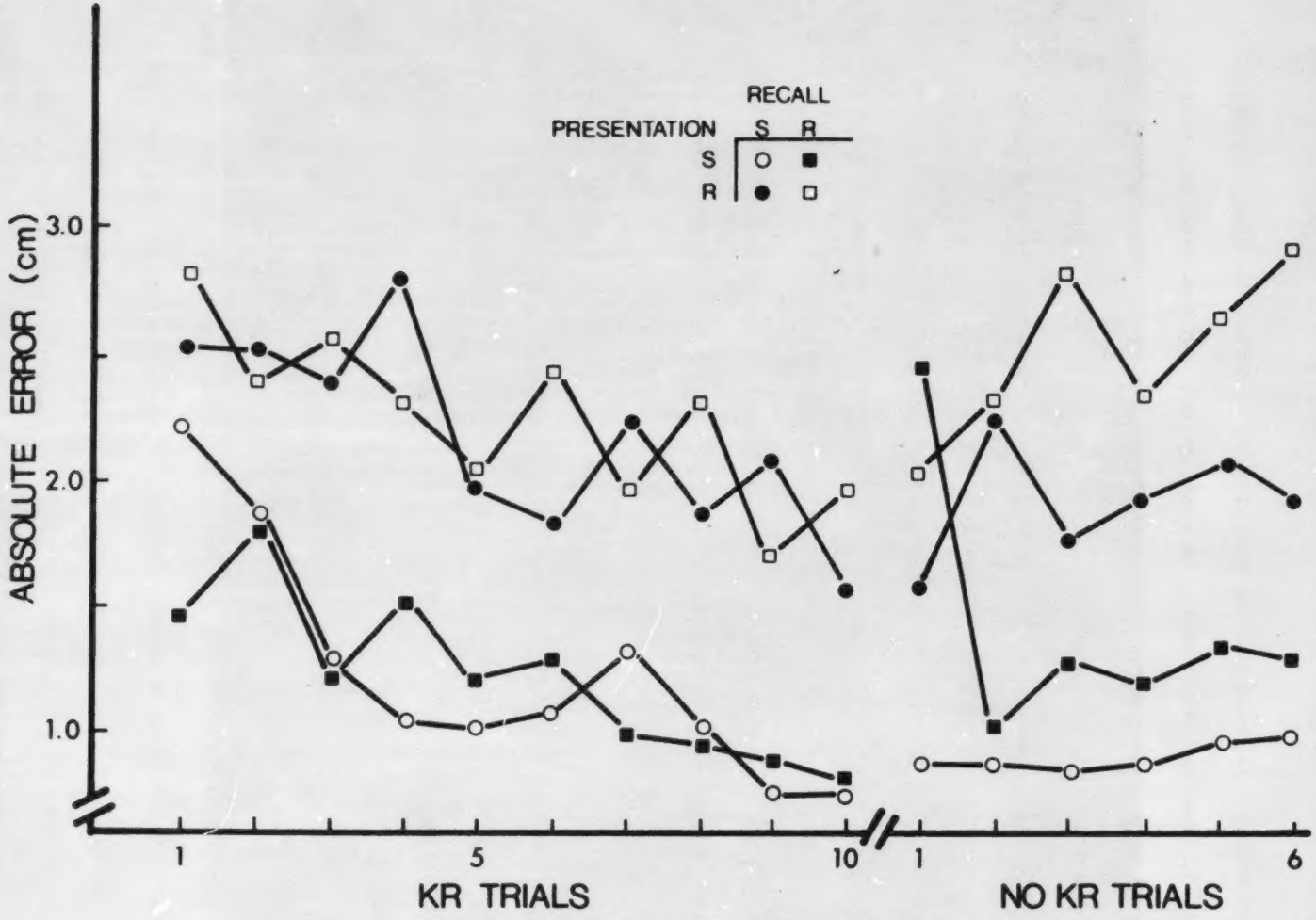

Figure 2. Absolute error as a function of KR trials (learning phase) and no KR trials (withdrawal phase) for the S-S, R-R, R-S, and S-R (S = SEQUENTIAL; R = RANDOM) groups.

the SEQUENTIAL-SEQUENTIAL and RANDOM-RANDOM groups match the learning phase of the same groups in the preceding experiment.

In the withdrawal phase for AE, the Groups, Movements, Groups x Movements, and Groups x Trials interactions were significant ($p < .001$). Similar to the withdrawal phase, effects involving the Movement factor were characterized by a positive correlation between length and error. The Groups effects, however, tell most about the organizational effects. The SEQUENTIAL-SEQUENTIAL group is again superior and differs from the SEQUENTIAL-RANDOM group only for Trial 1. The RANDOM-RANDOM group is again the lowest, with the RANDOM-SEQUENTIAL group placed between the SEQUENTIAL-SEQUENTIAL and SEQUENTIAL-RANDOM groups and the RANDOM-RANDOM group.

The CE effects mirrored the AE data except for a bowed trend characterized by least bias at both short and long movements. In most instances, CE was near zero and positively biased.

Figure 2 clearly indicates that the SEQUENTIAL-SEQUENTIAL group does not differ from the SEQUENTIAL-RANDOM group in withdrawal. Therefore, it can be concluded that perceptual motor organization effects are not limited to structured situations. Movement components learned under an organized regimen can be performed as well in a novel situation, i.e., a random order. A memory of nonrigid structure and strong representation is therefore indicated. The efficacy of perceptual organization is further supported by the superiority of the RANDOM-SEQUENTIAL group over the RANDOM-RANDOM

group in withdrawal. Since the only difference between the two groups is the sequential reproduction in withdrawal, the difference must be attributed to organization. Note, however, the first withdrawal trial for the SEQUENTIAL-RANDOM group. This point differs for the SEQUENTIAL-SEQUENTIAL first trial point. After consultation with each subject, it is suggested that it took one trial for subjects to refocus their perception and reorganize the task. Further, with respect to sequences and interval sizes, all subjects in the SEQUENTIAL-SEQUENTIAL and SEQUENTIAL-RANDOM groups immediately or by Trial 5 noticed the sequential order in the appropriate phase and all subjects were sure of equal interval sizes by Trial 2 in the appropriate phase. It is also interesting to note that few subjects in the RANDOM-RANDOM and RANDOM-SEQUENTIAL groups noted the organization. Only when organization was presented in the withdrawal phase for the RANDOM-SEQUENTIAL subjects was it detected. In summary, organization presented by the experimenter to the subject (EPO) is a potent variable in motor learning, supporting a dynamic view of motor learning.

Subject Discovered Organization

With the process of EPO more clearly understood, we turn to a free recall situation for movement information. Relevant theoretical questions are: (a) Does reproduction performance improve with subjective organization? (b) Do subjects develop a consistent reproduction order?

To gain some insight into the application of the free recall paradigm to motor learning, 4 additional trials were given to the subjects in the 4 experimental groups of the experiment just discussed. Subjects were requested to show the experimenter each of the 5 movements, 1 at a time, in an order that would allow maximum accuracy. These reproduction movements were further constrained by the requirement that reproduction be in blocks of 5, each block consisting of 1 reproduction of each movement.

With respect to AE, there were significant effects for Groups, Movements, and the Movement x Trials interaction ($p < .01$). Again, Movement effects were related to error increasing as a function of length, especially in the RANDOM-SEQUENTIAL group. CE effects were related to increased positive bias as a function of length.

The results presented in Figure 3 support the memory strength and flexibility notions presented earlier. Namely, switching to a new experimental situation has little effect on performance when a strong memory representation is established through learning in an organized manner. With respect to subjects' organization techniques, all free reproduction attempts were done in a sequential manner. This is not surprising, however, since the subjects in the SEQUENTIAL-SEQUENTIAL, SEQUENTIAL-RANDOM, and RANDOM-SEQUENTIAL groups had experience with the sequential reproduction pattern. But what is surprising is the fact that subjects in the RANDOM-RANDOM group, when free to reproduce how they wish, choose a sequential pattern.

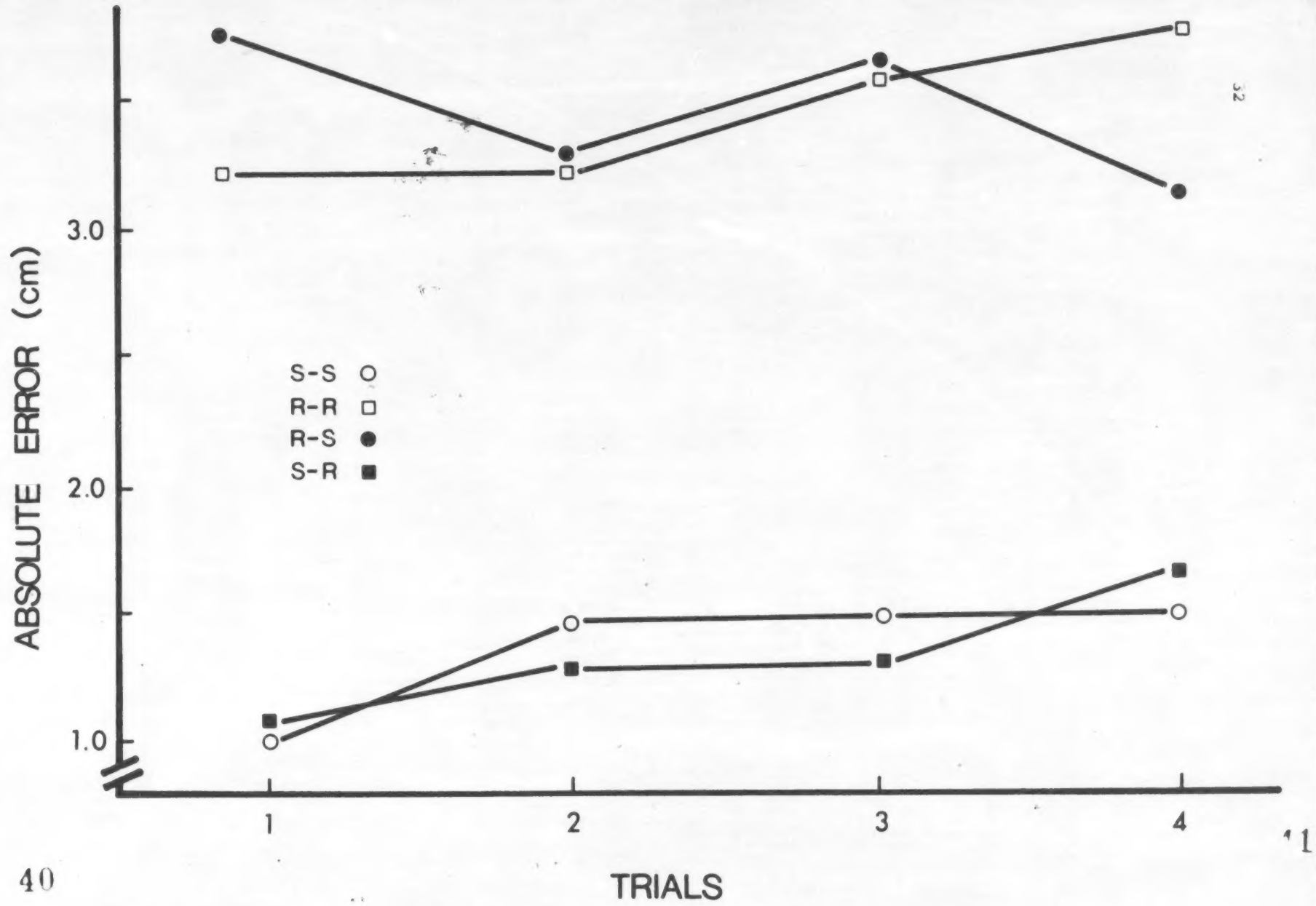

Figure 3. Absolute error as a function of the S-S, R-R, R-S, and S-R (S = SEQUENTIAL; R = RANDOM) groups in free recall.

The free recall findings just discussed provided some evidence with respect to free recall performance of movement information. More realistically, however, movements should be learned under conditions most conducive to SDO which do not bias reproduction order. This could be achieved by presenting the movements in random blocks of 5 with each block followed by the subject reproducing the movements in any order he or she wishes. This procedure would be strictly analogous to that used by Tulving (1967) in his free recall experiments. Two important questions can be answered by testing two groups, one with KR and one without KR. First, is KR unnecessary when a subject is allowed to organize in a free situation? Second, can subjects develop a consistent reproduction strategy?

Movements were presented in 10 random blocks of 5 movements each; all movements were made to a stop from the starting position. After each block of 5 movements was presented, the subject was asked to reproduce, in any order desired, each of the 5 movements presented by the experimenter. Each reproduction attempt was also made from the starting position. It should be clearly pointed out that no reproduction attempts were made until all 5 movements were presented, resulting in the following repeating sequence: 5 presentations--5 reproduction attempts. As in the EPO experiments, the instructions stressed reduction of error and further stressed establishment of a consistent reproduction order that would permit such error reductions. When KR was an independent variable it was given after <u>each</u> reproduction attempt.

For both the KR group and the no KR group the Trials effect was significant in AE ($p < .05$). For CE, the no KR group was characterized by large error at 50 cm. No other effects were significant and even at a liberal probability level, the Groups did not differ, as shown in Figure 4.

There is clear evidence that learning has occurred without KR, specifically, without verbal KR given to the nearest millimeter. The fact that the KR and the no KR groups did not differ, suggests that KR is unnecessary when the subject is free to reproduce in his or her own way. Organization therefore is cast as a potent process even in unstructured situations.

With respect to reproduction order, the subjects in the no KR group all established a linear reproduction order. Four of 6 subjects reproduced in a strictly linear manner (1-2-3-4-5), while the other two subjects also reproduced linearly in an order such as 5-4-3-1-2. The KR group had 5 of 6 subjects reproduce in the strictly linear manner, while the other group reproduced in the order 1-2-3-5-4. Therefore, under the constraints of the task, it appears that subjects can organize in a free recall situation, reduce error independent of verbal KR, and prefer to do so using a linear reproduction strategy.

The finding of learning without KR is to some extent surprising and suggests and SO can replace KR in certain situations. But such a finding bears replication to further differentiate, both theoretically

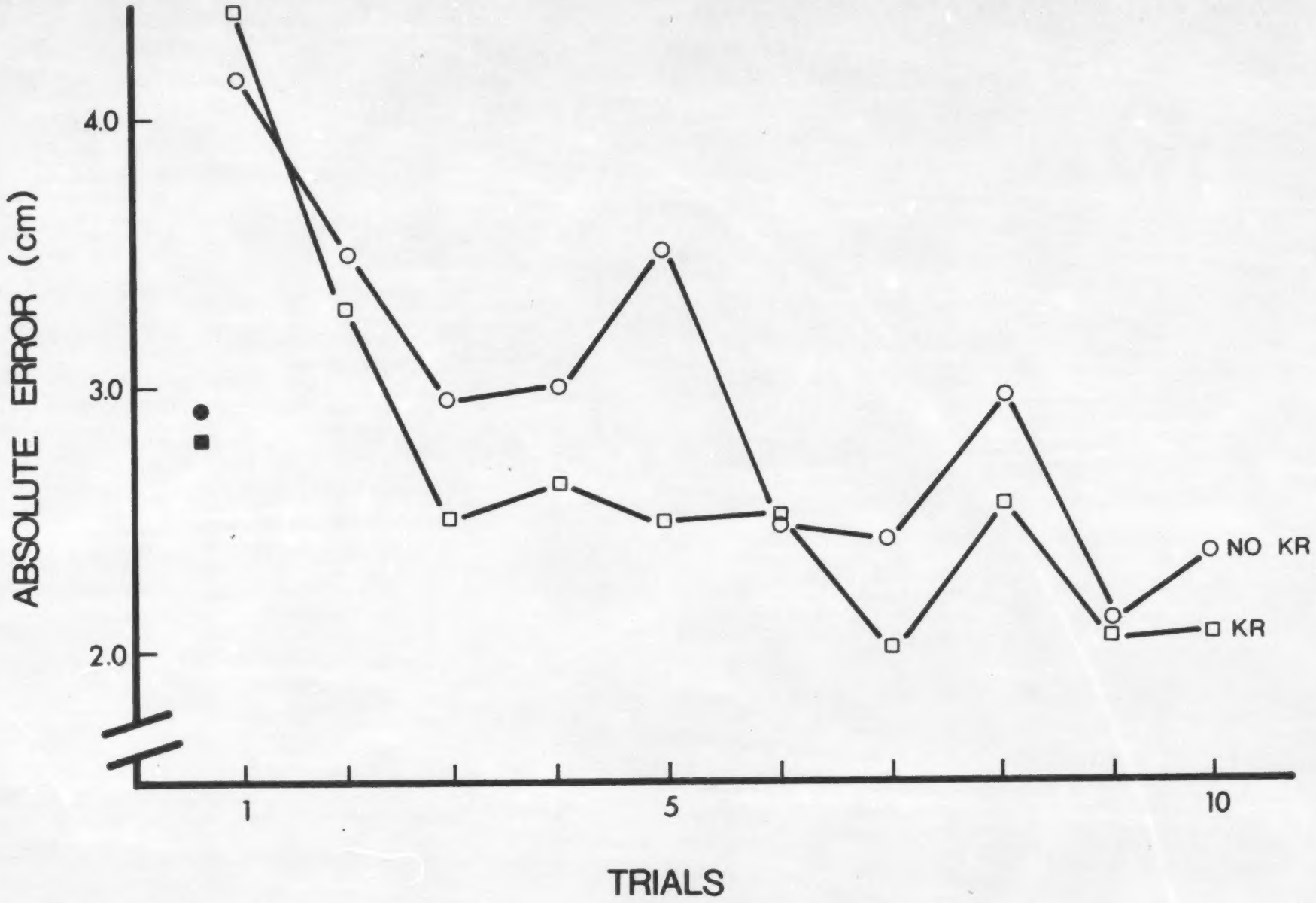

Figure 4. Absolute error as a function of Trials for both KR and no KR groups in free recall.

and pragmatically, the interactive roles of KR and SO. It is possible that by systematically modifying and preventing SO, the contribution of perceptual motor organization can be more exactly isolated.

Three experimental groups (n = 10) were tested. The first group was a replication of the experiment just described: SO--half the subjects received KR and half did not. The second group was asked to reproduce movements from shortest to longest. This group was labelled EPO and again half the subjects received KR. Finally, a group termed forced random (FR) was required to reproduce in the random presentation order used each time regardless of the presence or absence of KR. All other procedures were identical to those reported earlier except that an additional 6 trial blocks were given where, in the case of KR conditions, KR was withdrawn. The first 10 trials were termed Phase 1 and the remaining 6 trials, where neither group received KR, were labelled Phase 2.

The CE data tend to support the AE data in all instances and, since no particular patterns of bias were apparent, only AE data will be discussed. The Groups, Movements, Trials, and Groups x KR Level x Trials interactions were all highly significant in Phase 1 ($p < .025$). From Figures 5 and 6 it can be seen that, when organization was available, KR was again found to be unnecessary for learning to take place. This must be the case since learning occurred in the SO and EPO groups even when an external error report was not given. In addition, since learning is not nearly as proficient when

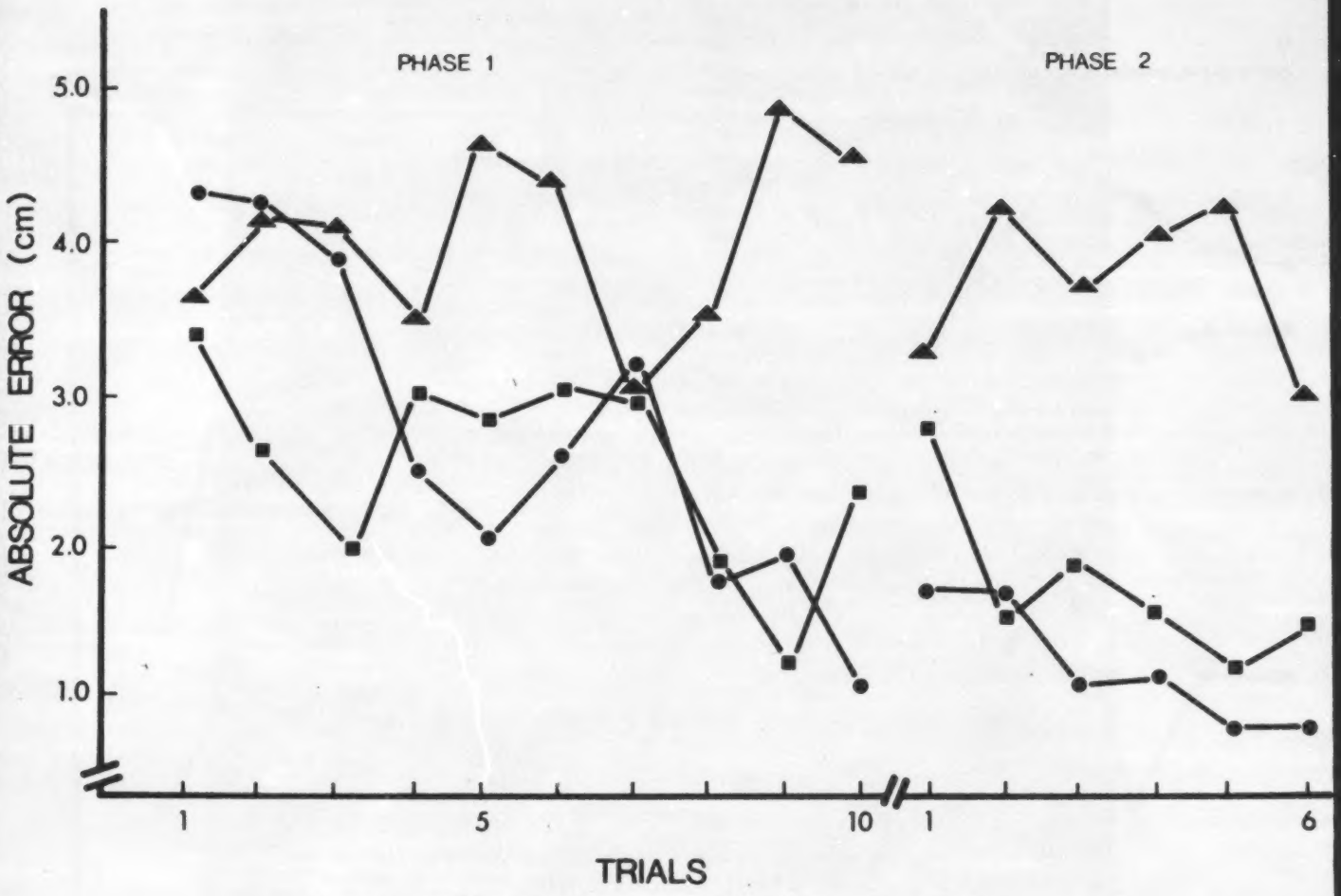

Figure 5. Absolute error as a function of Trials in Phase 1 and 2 for the no KR groups in free recall (● = SO; ■ = EPO; ▲ = FR).

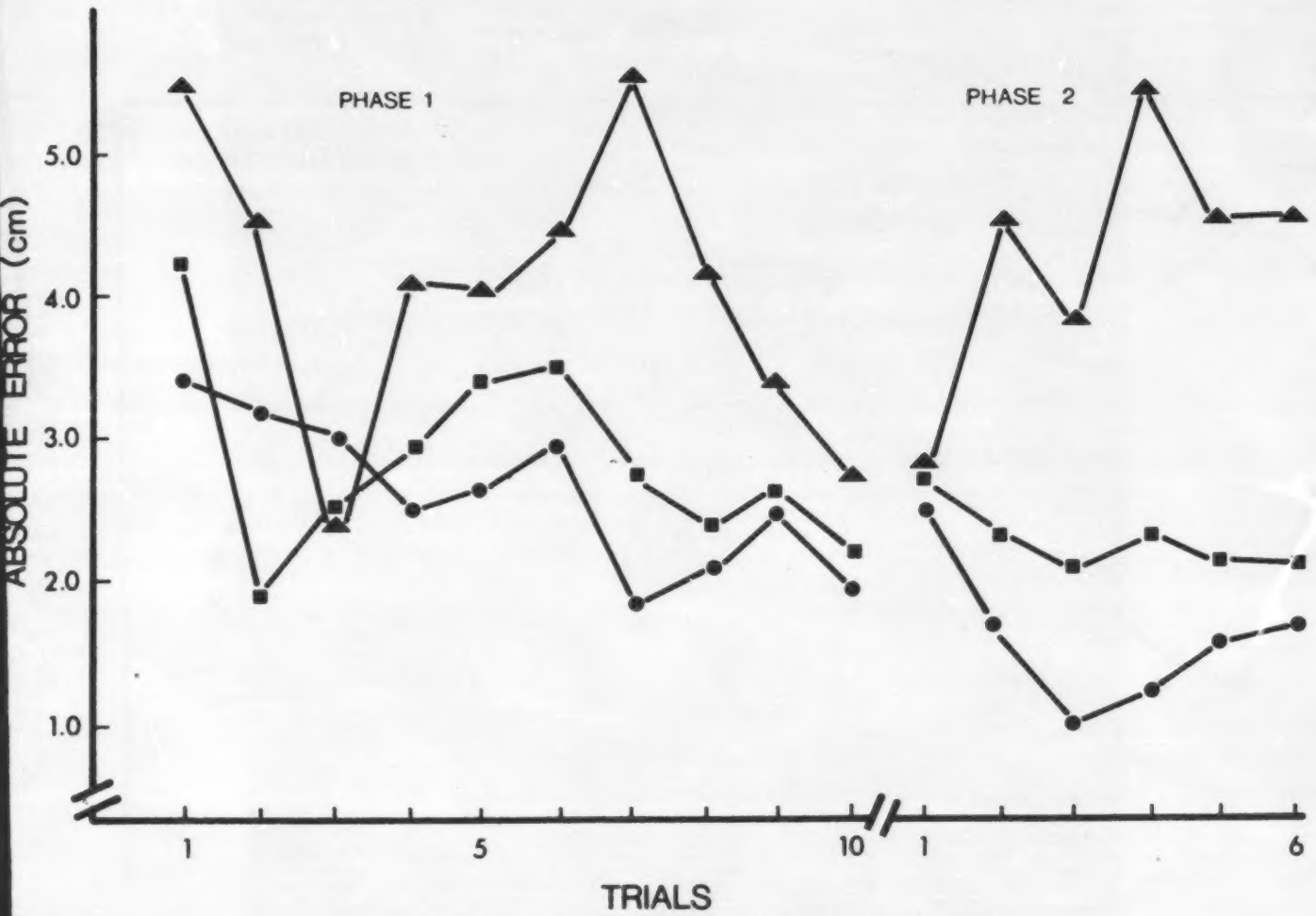

Figure 6. Absolute error as a function of Trials in Phase 1 and 2 for the KR groups in free recall (● = SO; ■ = EPO; ▲ = FR).

organization is prevented and KR is present, as is the case in the FR group, organization is left as the only variable that could be causing the learning effect in both this and the previous experiment. With respect to the Movement effect, the trend for increasing error with length was again noted.

The Phase 2 data were highly supportive of the role of organization in motor learning. A significant Groups effect ($p < .001$) demonstrated that SO allows more accurate performance than EPO, and both organized groups were better than the FR group. The fact that error varies as a function of level or organization is strong converging evidence that organization, not KR, was the important variable in operation.

Again, Movements effects were caused by the increasing error associated with length. However, the most interesting finding revolves around the main effect of KR levels ($p < .005$) where it was noted that the best performance was Phase 2 based on previous trials without KR. When this fact is considered along with the significant interaction of Groups and Trials ($p < .025$) plotted in Figures 5 and 6, the resilience of the organized memory representation is obvious.

In summary, just as was the case for EPO, SO is a strong variable for motor learning. However, now it appears that performance is best in a situation where the subject initiates the organization even though the organization is almost exactly the same. This statement

can be made since the SO groups, almost without exception, chose to reproduce in a sequential manner. Finally, and perhaps most importantly, it appears that in certain situations learning can occur (based on organization) without KR and without the necessity for previous trials where KR was given.

Summary and Future Directions

With respect to the theoretical questions related to perceptual organization, various important conclusions are possible. First, experimenter presented organization is an important factor in motor learning only when the subject is able to actively seek and utilize organization; mere presentation of organization is not sufficient. This suggests that the experimenter must carefully instruct subjects to realize the full benefits of organization on memory representation; what the subject is perceiving and processing is not necessarily what is in fact occurring.

No less important is the fact that individual memory representations, built up through presentation of organized stimuli, are not locked to that organization. In other words, reproduction of individual movements under KR withdrawal conditions did not depend on the learned organizational sequence. Therefore, a possible conclusion is that the effects of perceptual organization can be generalized to new or altered experimental situations. Taking the results one step further, perhaps the effects of perceptual organization can be generalized to novel, everyday movement situations.

Free recall paradigms tell us much about the learning process for movement. Subjects quickly established an optimal reproduction order and, more importantly, learning occurred independently of the presence or absence of verbal KR. In fact, the results strongly supported the dynamic role of the subject for learning of movement.

The future holds much promise beyond the results presented here. More work is needed to further define and differentiate the effects of subject discovered and experimenter presented organization. More specific work is needed on the relationship between perceptual motor organization and recall, recognition, and retrieval, as well as long- and short-term memory. Of course, other researchers will consider how perceptual organization relates to more ecologically valid movements such as those made in two- and three-dimension, those that are time and/or speed stressed, and those made with and without the presence of efference. Research is also needed to determine how perceptual organization changes with development and how learning based on organization may be facilitated at different age levels.

Perceptual organization may also be found to directly affect movement organization for response execution. But a word of caution is in order. Research must be extensive and systematic, not haphazard, as it has been in the past. More importantly, researchers in motor learning must not blindly adopt verbal theories and methodologies. Instead we should borrow from verbal theory as an impetus for our own work only when necessary and strive to retain the uniqueness of the motor system and not allow it to be masked by these verbal theories.

In conclusion, the present series of experiments by no means answers all the questions about perceptual motor organization. However, this author feels that it provides a much needed start toward an empirical and theoretical analysis of this crucial process

in motor learning. As research continues, both theoreticians and practitioners will benefit. As theories and models of motor learning--specifically perceptual motor organization--are established, this knowledge will be used to aid in the teaching and rehabilitation of motor skills.

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